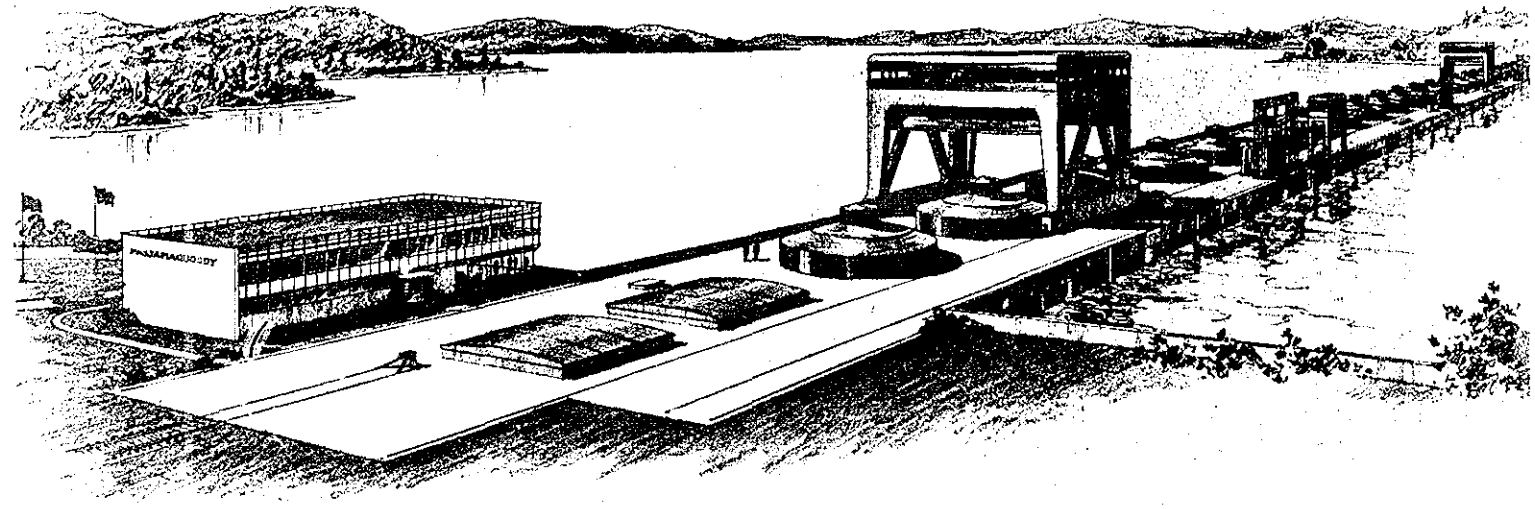
THE INTERNATIONAL PASSAMAQUODDY TIDAL POWER PROJECT



A technical briefing of the
International Passamaquoddy Engineering
Board Report of October 1959 to the
International Joint Commission,
United States and Canada

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International Passamaquoddy Tidal Power Project

Briefing of I.P.E.B. Report of October 1959

OPENING STATEMENT

The purpose of this presentation is to describe briefly the investigations conducted and the conclusions reached in the study of tidal power development in Passamaquoddy Bay in Maine, U.S.A., and New Brunswick, Canada, during the period 1956-59. The investigation was performed under the direction of the International Joint Commission. This briefing will follow closely the content of the International Passamaquoddy Engineering Board report of October 1959. The first three chapters of the report formally introduce the authorized survey, establish the scope of the investigations, and present basic data. The next three chapters present the technical design of the tidal project, designs of auxiliary projects, and development of costs. The following three chapters cover economic effects of the project, power utilization, and project evaluation. The final chapter contains the conclusions.

CHAPTER I - INTRODUCTION

In accordance with United States Public Law 401, 84th Congress, 2nd Session, and the Boundary Waters Treaty of 1909, the Governments of Canada and the United States on August 2, 1956 directed the International Joint Commission to investigate the engineering and economic feasibility of harnessing the tides of Passamaquoddy and Cobscook Bays in New Brunswick and Maine to produce hydroelectric power. The investigation, completed in October 1959, established the type and cost of the most economical project to generate electricity from the tides, and determined the cost of power from the most economical alternative source as a measure of economic feasibility.

To carry out the investigation of the tidal power project and its effect on the economies of the United States and Canada, including the fisheries of the area, the Commission established two separate boards, the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board. Composed of two representatives each from Canada and the United States, the Boards were directed to coordinate their studies and to submit separate reports to the Commission. The Engineering Board, in turn, established an Engineering

Committee to supervise the detailed investigations. These investigations were carried out primarily by the U.S. Army Engineer Division, New England, Corps of Engineers, and the Regional Office of the United States Federal Power Commission, New York. Canadian aspects of the survey were conducted by the Department of Public Works, the Department of Northern Affairs and National Resources, and other agencies of the Federal and Provincial Governments of Canada.

Advice and assistance were obtained from several federal, provincial, and state agencies and from many private concerns and individuals in both Canada and the United States.

This briefing is based on the engineering report of the investigation and does not cover any of the activities of the Fisheries Board. However, the monetary damages and benefits determined by the Fisheries Board were considered in the engineering report.

POWER FROM THE TIDES

Tidal hydroelectric power, like river hydro power, can be produced by a flow of water from a higher to a lower level through hydraulic turbines. A single pool equipped with gates may be built to trap water at high tide and discharge through turbines to the ocean at low

(Slide 1-3: Single pool plans)

tide, or the pool may be emptied at low tide to receive turbine discharge from the ocean at high tide. Two separate pools equipped with filling and emptying gates may be used, one pool filled at high tide and the other emptied at low tide, with the high pool discharging through the turbines into the low pool.

A single high pool has the serious disadvantage of producing discontinuous power, because no power can be generated without a sufficient difference between the level of the pool and the level of the ocean. Thus no generation is possible until the ocean has receded sufficiently to obtain this difference in water levels, or power head; nor is generation possible on the rising tide after the level of the ocean becomes too high to provide this minimum necessary head. For similar reasons, a single low pool also produces interrupted power. This disadvantage is avoided in the two-pool plan, the plan adopted for the project described in the engineering report, which generates varying but continuous amounts of power. This continuous power is achieved in the two-pool plan by varying the operation of the turbines so that the level of one pool is always sufficiently higher than the other.

(Slide 4-10: Typical two-pool tidal plant operation)

The advantages of a tidal power plant are that

the tides, which can be predicted with accuracy for many years in the future, can produce power unaffected by droughts, floods, ice jams, or silting -- adverse factors which decrease the output and limit the life of river hydroelectric plants. An inherent disadvantage of the tides as a source of power is that the tides, following the gravitational pull of the moon as it passes overhead every 24 hours and 50 minutes, are out of phase with the 24-hour solar day. This 50-minute daily lag is fundamental to the economics of tidal power. Since power output varies with the tides, tidal power is completely out of step with the normal patterns of daily use of electricity. Therefore, unless the tidal power plant is supplemented by an auxiliary power plant, such varying power would be of little value.

Tidal ranges, the height between high and low tides, determines the available head and thus governs the amount of power generated. Ocean tides are caused by the changing relationship of the sun, earth, and moon with respect to each other. The tidal range, which is affected primarily by the phases of the moon, also varies from day to day. As shown in the simplified illustration, the sun and moon appear on the same side of the earth approximately every four weeks, at the time of new moon. Two weeks later, at the time of full

(Slide 1-2: Phases of the Moon and Tidal Cycle)

moon, the sun and moon appear on opposite sides of the earth. When either of these conditions occurs, gravitational attraction of the sun and moon reinforce each other and cause maximum or spring tides. When the moon is at either quarter phase, the gravitational attraction of the sun and moon are approximately at right angles from the earth, causing minimum or neap tides.

A tidal power project requires a location where the tides are high, where one or two pools can be isolated from the ocean at a reasonable cost, and where suitable sites exist for the powerhouse, gates, and other necessary works. Passamaquoddy Bay meets these requirements very well. (Wall Display: Regional Map)

PREVIOUS INVESTIGATIONS

Before the present survey, the two principal investigations of the Passamaquoddy site were those made by Dexter P. Cooper from 1919 to 1933, and by the U.S. Army Corps of Engineers in 1935-37.

The Corps of Engineers project of 1935-37 was a single-pool development located entirely in the United States. At that time, a comprehensive program of field exploration and laboratory testing was started and partly completed, and many design studies were made before the project was stopped. Most of the data and analyses were preserved and proved of great value to the current survey.

CHAPTER II - COMPARISON AND SELECTION OF PROJECT PLANS

TIDAL PROJECT

There are many ways in which one or two pools can be isolated from the ocean at the Passamaquoddy site. Any of the previously described methods of operating a tidal project could be used. I will discuss the studies leading to selection of the plan shown on the wall map as the arrangement best suited to the Quoddy site and region.

(Wall Display: Selected Plan, General Arrangement)

Preliminary studies showed that project cost increases rapidly with the generating capacity of the powerhouse. Thus, least costly tidal power requires that each kilowatt of capacity generate as much energy as possible. The one-pool Quoddy project started in 1935 was not promising in this respect since it would generate energy at an average of about 25 percent capacity. A two-pool project would generate energy at more than twice this rate.

One-pool and two-pool projects were compared further by computing the annual energy which the various types of projects could generate at the Passamaquoddy site. The results of these studies are summarized in this slide. The vertical scale on the graph is annual energy in millions of kw.-hr.; the horizontal scale is

(Slide 2-1: Annual Energy, Single and Two-Pool Projects)

the number of generating units. The curves show that a two-pool project with about 30 units has the advantage of generating as much energy as the best one-pool project with 50 units. Two-pool power with lower peak output could be used to better advantage in the power market area and could be transmitted at lower cost. Still another advantage of the two-pool project, and a very important one, is that generation, being continuous, would provide some dependable capacity. The one-pool project does not yield continuous power and, therefore, has no dependable capacity. On the basis of these considerations, one-pool projects were eliminated from further study.

Many different two-pool arrangements were studied to determine which would be most satisfactory. An important tool in these studies are the curves shown on the next slide. The vertical scale on the graph is in millions of kw.-hr. per generating unit per year; the horizontal scale is the pool area in square miles per generating unit. The curves permitted a quick estimate of annual energy, once the area of the pools was determined and the number of turbines selected for a tidal power project at the Passamaquoddy site. The separate curves on the graph show that more tidal energy would be generated as the two pools become more nearly equal in size.

(Slide 2-2: Annual Energy, Two-pool projects)

The many two-pool arrangements examined vary in the location of dams, in the use of either bay as the high pool, in the location and size of the powerhouse, and in the location and number of filling and emptying gates. A preliminary estimate of cost and power output was made for each plan. The ratio of project cost to annual energy output was used as an index in selecting the more favorable layouts. We called this ratio the "comparative index." The lower the index the more favorable the arrangement.

The two-pool arrangement that was selected for designs and estimates is shown on this wall display. A dam in Western Passage and a series of dams from the north end of Deer Island to the Canadian mainland would close Passamaquoddy Bay from the ocean to form a high pool with an area of 101 sq. mi. This pool would be filled during high tides through 40 gates in Letite Passage and 50 gates on Deer Island Point. Dividing the flow to the upper pool between the two passages reduces both the construction cost and hydraulic losses in the channels.

(Wall Display: Selected Plan, General Arrangement)

The low pool with 41 sq. mi. would include Cobscook Bay and would extend to dams in Quoddy Roads and in Head Harbour Passage. Seventy gates for emptying the low pool would be located between Pope and Green Islets.

A powerhouse with a rated capacity of 300,000 kw. would be located between the two pools in a channel excavated through Moose Island at Carryingplace Cove. The arrows show the direction of flow through the filling gates, powerhouse, and emptying gates.

Two navigation locks for vessels moderately larger than those in current traffic would be provided, one in Head Harbour Passage and one in Western Passage. Two smaller locks, one at Quoddy Roads and one at Little Letite Passage, would accommodate fishing vessels.

AUXILIARY PROJECTS

The amount of energy available from the selected two-pool tidal project would vary with the ebb and flood of the tide. The time of occurrence of minimum and maximum output would vary periodically with the lunar day which is 50 minutes longer than the solar day. As the normal pattern of power demand follows the solar day, the maximum power demand may occur at the minimum or any stage of power output.

The output of the tidal plant alone for three consecutive weeks, compared with a typical load curve of the combined utility loads in Maine and New Brunswick, expected in about 1975, is shown on the next slide. The load factor of this load curve is 60 percent, i.e., the ratio of average output to peak demand.

(Slide 2-5: Output and Load Pattern, Tidal plant alone)

For load-carrying purposes, the dependable capacity of the tidal project is limited to the capacity available under the most adverse conditions. All output in excess of this capacity would have value only as non-firm or secondary energy. This excess generation is considerable and to make it dependable for serving the predicted load demands, it must be firmed up by the use of an auxiliary source of power. Three different types of auxiliary power sources were studied during this survey.

One method of firming the tidal plant output would be to store a portion of the tidal plant energy by pumping water to a storage reservoir during times of high tidal plant output. The stored water would then be used to generate power when the tidal plant output is low. By alternately pumping and generating, the pumped-storage auxiliary would regulate the tidal plant output to meet the varying load demand. The pumped-storage operation would actually result in a decrease in total energy because of pumping and regeneration losses. This type of operation is illustrated on the next slide which shows three typical weeks of tidal plant output modified by a pumped-storage plant to fit a predicted load pattern. The most favorable pumped-storage auxiliary project is the Digdeguash project on the Digdeguash River in New Brunswick, at the north end of Passamaquoddy Bay.

(Slide 2-6: Output and load pattern, tidal plant with pumped-storage)

Another method of firming the tidal plant output would be to add energy to the tidal plant output from an auxiliary power source such as a hydroelectric plant so that the combined tidal plant and auxiliary energy would form a pattern similar to the system load. This type of operation was assumed for analysis of auxiliary river hydro developments and is shown for three typical weeks of operation on the next slide. This plan is based on using the proposed Rankin Rapids development on the upper Saint John River as the auxiliary. The tidal plant outputs are plotted on the bottom of the system load, i.e., are "base loaded." The cross-hatched area above the base load represents the energy from the auxiliary. The remainder of the system load would be supplied by the remainder of the system generating capacity.

(Slide 2-7: Output and load pattern, tidal plant with auxiliary power)

The third type of auxiliary plant considered for firming the tidal plant output would be a conventional steam-electric plant. Preliminary analyses indicated that this type of auxiliary was less favorable than others considered.

Study of all available data led to the conclusion that the Rankin Rapids project on the Upper Saint John River in Maine would provide the largest power and storage potential with the lowest at-site cost of any

single project or combination of river hydro projects considered feasible for development. The site is located on the Saint John River about 175 miles northwest of the site of the proposed tidal power project. The site was considered for development by the New England-New York Inter-Agency Committee and is discussed in the interim report on "Water Resources of the Saint John River Basin" submitted to the International Joint Commission on April 6, 1953. The level of development and project layout, however, was changed in the course of the current study.

The development of the Rankin Rapids site has received some opposition from people interested in preserving the fishing and white-water canoeing on the Allagash River which would be flooded by the Rankin Rapids reservoir. Because of this opposition, an alternate development was considered consisting of a high-head dam at Big Rapids, located on the Saint John River upstream from the mouth of the Allagash River, and a low-head project at the Lincoln School site located a short distance downstream from Rankin Rapids. However, the Rankin Rapids project would have a greater dependable capacity and would produce more power than the alternate combination of the Big Rapids-Lincoln School projects.

As a possible alternative method of firming the tidal project output, it was assumed that the Rankin Rapids project could be constructed with an initial installation of about 200,000 kilowatts to generate the energy available at the site for use in the utility markets of Maine. Additional capacity could be added to firm the varying tidal project output. Energy to support this incremental capacity would be borrowed from the basic Rankin Rapids project when the tidal power output is deficient (neap tide), and paid back when there is a surplus of tidal energy (spring tide). The annual generation of the tidal plant and incremental capacity at Rankin Rapids would be the same as for the tidal project alone. With 260,000 kilowatts of incremental firming capacity of Rankin Rapids, the combined dependable capacity would be 355,000 kilowatts at about 60% load factor.

COMBINATIONS FOR ECONOMIC ANALYSIS

On the basis of the foregoing, the following four plans of power development were selected for evaluation of costs and benefits:

(1) Tidal project alone.

(2) Tidal project and all of Rankin Rapids as the auxiliary power source.

(3) Tidal project and incremental capacity only at Rankin Rapids as the auxiliary.

(4) Tidal project and the Digdeguash pumped-storage project as the auxiliary.

It was assumed for this study that the United States and Canada would share equally both the costs and benefits of the four combinations.

CHAPTER III - SITE CONDITIONS

I will now describe the site conditions, including previous studies, current field investigations, foundation conditions, and availability of construction materials.

TIDAL PROJECT

Much of the basic data compiled by existing agencies in the United States and Canada was used in the survey. In addition, data developed by Dexter P. Cooper in the 1920's, and by the U.S. Army Corps of Engineers in 1935-37, were used where applicable. Before the project was stopped, the Corps built two small dams between Pleasant Point and Moose Island which are in use for Maine State Highway No. 190, and which would form a part of the project as presently proposed.

A field office and a soils laboratory were established in Eastport, Maine. The topographic and hydrographic surveys, tidal observations, subsurface explorations, and laboratory testing were supervised from that field office. The largest single phase of the field investigations was the deep-water drilling, costing about $500,000. Depths up to 300 ft., velocities up to 10 ft. per sec., and tides up to 26 ft. were encountered. A specially rigged, 240-ft. drilling

barge was towed from Houston, Texas, to drill the 15 deep-water holes.

Tidal project power is directly related to tide range. The mean tide range at Eastport is 18.1 ft., the maximum, 25.7 ft., and the minimum, 11.3 ft. Of great importance during construction is the tidal current velocity which now runs up to 10 ft. per sec. in some locations. Most of the project areas are protected from waves. The exposed parts could receive waves up to 12 feet high.

(Wall Display: Selected Plan, General Arrangement)

At the tidal project, bedrock is exposed or occurs at shallow depths in locations selected for all major concrete structures and in some of the tidal dam locations. All structures, except the dams, would be founded directly on sound bedrock. Overburden covers most of the ocean floor in the project area. The thickness and physical characteristics of this overburden depend on several factors, including the amount and type of material deposited during glaciation, post-glacial erosion of the land mass, and effect of tidal currents. Marine clay occurs in some of the tidal dam foundation areas and in the powerhouse headrace in Carryingplace Cove. About 17 million cu. yd. of clay must be excavated. Construction materials available from excavation for project structures, and from borrow

areas nearby, would be adequate for constructing the tidal dams. Suitable concrete aggregates can be produced from local bedrock outcrops.

AUXILIARY PROJECTS

At the Rankin Rapids river hydro site on the upper Saint John River the bedrock valley walls of indurated shale are generally covered by dense glacial till, with a terrace of stratified sand and gravel just above stream level on the left bank. The preglacial bedrock valley extends about 80 ft. below present stream level and contains a deep deposit of glacial silt. The site is adequate for construction of an earth dam. Suitable construction materials occur in the immediate vicinity. Local materials are not suited for producing high-quality concrete aggregates. The nearest known source of sound aggregates is at Deboulie Mountain about 16 miles south of the project site. (Wall Display: Regional Map)

The Digdeguash pumped-storage site is in an area of sound bedrock partly covered by dense glacial till. Either a concrete or rock fill dam could be constructed with locally available materials.

CHAPTER IV - TIDAL PROJECT DESIGN

There are several important components of the selected tidal power project. I will describe briefly the major features of the dams, cofferdams, powerhouse, filling and emptying gates, navigation locks, relocations, and the power plant output and capacity.

(Wall Display: Selected plan, general arrangement)

DAMS AND COFFERDAMS

The selected plan of development includes 35,700 lin. ft. of tidal dams with a gross volume of 53 million cu. yd. Half the length of the dams lies above el. -25, and only 8 percent extends below el. -125, m.s.l. to a maximum depth of 300 feet.

Foundation conditions vary considerably in the project area; the selected layout shown on the wall map places the dams on the best foundations possible. Even so, some of the dams are located where clay occurs in the foundation, making it necessary to use a wider section than would be needed on the stronger granular or rock foundations. Careful study was made to make best use of the large amount of material excavated for structure foundations and channels, particularly the clay removed from Carryingplace Cove.

The influence of construction methods on design of tidal dams is largely in cost and seepage control.

Large quantities of materials must be transported and placed at minimum practicable cost consistent with securing a safe and adequate dam. Three methods of placing materials are suited for the conditions of the Quoddy site. Land-based operations, using end-dump trucks working outward from the shore, and marine construction, using bottom-dump scows, are satisfactory where control of placement or where loss of fines is not critical. Bottom-dump buckets, lowered through the water, would be used where necessary to prevent excessive loss of fines.

Hydraulic model tests were performed to investigate methods of underwater construction and closure of the tidal dams. These tests were conducted under the direction of Dr. Lorenz G. Straub at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota.

The hydraulic model tests were conducted at a scale of 1 to 100 in flumes with separate water sources and movable weirs at each end. Motorized devices operated the weirs continuously so that water surfaces would represent the conditions at the dams and simulate the ebb and flow of the tides across the partly built dams.

It was quickly determined that the rockfills, including closure of the crest in and above tide range,

could be built with quarry-run stones with a maximum size of about 1 cu. yd. This is a substantial reduction from the maximum size stone planned in the 1935-37 design. This reduction is due largely to the benefit of using the filling and emptying gates to pass flows during closure of the dams.

Small-scale model tests are not suitable for investigation of underwater embankment construction with cohesive materials. Therefore, Dr. Straub's model test program did not include use of clay in the dams. Only granular materials were used in the model embankments to reduce and control leakage. These tests showed the necessity for the bucket-type placement of granular materials to prevent excessive loss of the finer sizes of particles in deep water.

The fundamental type of structure most appropriate for the tidal dams is a rockfill embankment. This type was selected because rock is the easiest material to place under water and because large amounts of rock would be excavated during project construction. Furthermore, additional rock may be obtained readily, if needed. Impervious materials to prevent or control leakage through the dams may be placed in a central core or as a blanket on one side of the rockfill. The central core was adopted as better suited for the

tidal dams, particularly for the deeper passages and for locations where clay occurs in the foundation.

The selected design, with clay core above el. -125, is shown in the center of this slide as applicable in Head Harbour Passage, east of the emptying gates. The dark shading indicates gravel and sand which would be placed by bucket below el. -125 and above el. -25, and dumped from scows between these elevations. The outer, lightly shaded areas indicate rockfill. Placing the materials in reversing tidal currents would blend them as indicated by the interweaving of successive layers. The widened base below el. -150 is necessary to spread the embankment load over the foundation in which clay occurs. This basic section was applied elsewhere with modifications to adapt it to local conditions. The total leakage has been estimated at 500 c.f.s. for this design. This amount is so small that power production is not affected.

(Slide 4-4: Tidal Dams, Selected Design)

Cofferdams in water more than 60 feet deep would be embankments similar to the permanent dams. The hydraulic heads on the cofferdams would vary up to 75 feet, exceeding that on the tidal dams. Lesser cofferdams would be principally steel sheet pile cells.

POWERHOUSE AND SWITCHYARD

The powerhouse design is based on using 30 turbines of 320-inch diameter,--the largest size that can be

conveniently manufactured and transported. A speed of 40 r.p.m. was selected as a compromise between better turbine efficiency at a lower speed, and lower generator cost at a higher speed. It was found that using either a fixed-blade or a Kaplan (adjustable-blade) turbine would result in about the same cost for tidal power. A fixed-blade turbine was selected because of the lower maintenance costs of the simpler mechanism. The average head on the turbines would be only 11 ft.

The direct-connected generators rated at 10,000 kw., were selected to provide the least costly tidal power. The rating is very low considering the fact that the turbines are as large as can be built. The generators could be operated continuously at 15 percent overload at an elevated, but permissable, temperature.

Stone & Webster Engineering Corporation of Boston, Mass., was engaged to design the powerhouse around the turbines and generators I have just described. The powerhouse would be the outdoor-type, with a total length of 2,580 feet. Office buildings and erection bays would be constructed at each end of the powerhouse.

The size of water passages established the main floor levels of the powerhouse, the lowest being at el. 12 as shown on the next slide. The next deck, at

(Slide 4-7: Powerhouse Typical Section)

el. 27, was made the roof deck, since it would be well above maximum tide level of el. 13.9. Each unit would be 78 ft. wide and 176 ft. long.

The generators would project above the roof deck, enclosed in weathertight housings of steel. The main power transformers would be located on the intake side of the roof deck with the power and control cable and electrical equipment galleries located directly beneath. The gallery space on the downstream side of the main units would be used for mechanical equipment and piping.

Two large gantry cranes, would operate along the full length of the powerhouse and erection bays. Each crane would have large rolling doors to enclose the area under the crane for servicing the generating units during bad weather.

Prevention of corrosion of metals is particularly important at the tidal power plant because the turbines and other expensive metal equipment would be continually immersed in sea water. The most suitable corrosion resistant metal is a stainless steel containing nickel, chromium, and molybdenum, which would be used for important turbine parts that cannot be protected by other methods. Less expensive methods would be used for other metal parts.

The voltage of the generators would be stepped up for transmission by 4 main transformers. Two transformers

would have high voltages of 230 kv. for the distribution system in the United States. The other two transformers would have high voltages of 138 kv. for the distribution system in Canada. The switchyard, located at the north end of the powerhouse, would have two outgoing lines at each voltage.

FILLING AND EMPTYING GATES

The upper pool would be filled at high tide through 40 filling gates in Letite Passage and 50 filling gates at the south end of Deer Island. The lower pool would be emptied at low tide through 70 emptying gates in Head Harbour Passage.

The filling and emptying gates of a tidal power project must meet operating requirements not usually demanded of hydraulic gates of conventional hydro-electric projects. The tidal project gates must be capable of passing, with minimum loss, an unusually large volume of water at low head. The gates must be rugged, reliable, easily repaired, and capable of being opened or closed with a minimum amount of power. All of the gates must be operated twice during each tidal cycle. The 160 gates would move nearly a quarter of a million times every year.

The problem of tidal gates was studied thoroughly to determine the type of gate which would result in the

least costly tidal power without reducing the reliability of the power. A particular problem is the wind-driven spray which could freeze on exposed slots, hoists, cables and sheaves. The extensive studies showed that vertical lift gates in submerged passages, as shown on the next slide would be least costly and would provide reliable operation and ready means for inspecting, maintaining, and replacing the gates. The filling gates would be 30 ft. square with the sills at el. -40. Emptying gates of the same size would be set 13 ft. lower, but otherwise would be similar to the filling gates.

(Slide 4-9: Filling Gate)

The gate structures and gates were designed for the water levels, heads, and maximum wave heights that could occur during construction and operation of the project. The designs of gates and operating equipment are adequate to function during any stage of tide and pool levels. The venturi tubes are designed for all flow or pressure conditions that may occur when a gate remains open with flow in either direction.

Since a large number of gates must be opened and closed frequently and within a short time, it is important to minimize the power required to operate the gates. Each gate would be counterweighted and operated by an individual hoist powered by a $1\frac{1}{2}$ hp. electric gearmotor. Movement of the gates would be

started in sequence in a 1-minute period and would open or close in about 5 minutes.

NAVIGATION LOCKS

Existing and prospective future marine traffic in the tidal project area were studied to establish requirements for navigation locks. The largest vessels using Cobscook Bay in 1954-58 were three oil tankers that regularly serve tank farms at Garnet Point. The largest of these is 300 ft. by 43.2 ft. with a draft of 16 ft. Traffic through Quoddy Roads normally consists of fishing vessels, the largest being 84 ft. by 19 ft. with a draft of 10 ft. The largest composite dimensions of vessels recorded in Passamaquoddy Bay in 1954 were 329 ft. by 50 ft. with a 19-foot draft. The traffic through Letite Passage consists mainly of smaller fishing vessels with dimensions not usually exceeding 62.5 ft. by 16 ft. and 7.7-foot draft.

(Wall Display: Selected Plan, General Arrangement)

It is planned that navigation access to the tidal project pools would be maintained during and after construction of the project. Locks in Head Harbour Passage and in Western Passage would have clear dimensions of 415 ft. by 60 ft., with a 21-foot depth at mean low water. Thus, vessels moderately larger than those now using the area could enter the pool areas. Locks in Little Letite Passage and in Quoddy Roads would be 95 ft. by 25 ft. with a depth of 12 ft.

(Wall Display: Selected Plan, General Arrangement)

A possible future lock of large size could be constructed in Little Letite Passage if justified by the need for larger vessels to enter Passamaquoddy Bay.

The walls of the lock chambers would be reinforced concrete of semi-gravity type of design. Lock gates would be the double-leaf sector type, selected primarily for ability to function under reversing head conditions. These sector gates would be used for filling and emptying the locks, except that short by-pass culverts would be used for the initial stage of filling when the head exceeds 12 ft. Single-leaf bascule type bridges would be constructed across the locks for access to all parts of the tidal project. These bridges would have sufficient underclearance to permit passage of small vessels without opening the draw bridge.

OTHER FEATURES

The International Passamaquoddy Fisheries Board requested that fishways be provided in the tidal project for the passage of anadromous fish. In accordance with this request, two fishways were included in the project plan, one at the emptying gates and the other at the powerhouse.

Relocation of all existing public and private facilities that would interfere with the construction and operation of the tidal project were included in

the project cost estimate. The facilities would be relocated as necessary to provide the same service as before the project was constructed, without loss to the owner.

The largest single relocation arises from the need for cutting through the narrow neck of Moose Island for the powerhouse headrace. A new bridge would be constructed across the headrace to carry Maine State Highway 190, one track of the Maine Central Railroad, the water supply line to Eastport, and various power and communication lines.

The total land required for the tidal project is but a very small fraction of the total pool area which, in a conventional reservoir project, often constitutes a large part of the project cost.

About 365 acres of land would be required for the tidal project in the United States, and 1,540 acres in Canada.

In the high pool, the average change in pool level would be about 4 ft., instead of the present average tide range of 18.1 ft.; the average level would be about el. 6.3, instead of the present mid-tide el. 0. In the low pool, the average change in pool level would be about 7 ft.; the average level would be about el. -5.0. The shore installations in both the upper and lower pools

were surveyed to determine the damages resulting from these changes in tidal levels. The costs of damages were included in the project estimate.

The tidal project construction schedule is based on a 6-year program. About 2 years are needed before major work can be started to allow for design, purchase of major equipment and award of initial contracts for construction. Because material excavated for structures would be used to build the dams and cofferdams, all excavation must be carefully coordinated with the fill operations.

Construction of the project within a 6-year period would require working throughout the entire year, even though dense fogs and storms would, at times, hinder water transportation, and extremely cold weather would delay placing of concrete.

The overall project can be separated into construction contracts of reasonable size and duration to assure competitive bidding and to avoid the problems of large price level changes over extended periods of time.

The powerhouse would take the longest time to construct and complete the installation of turbines, generators and other equipment necessary for plant operation.

Construction of the filling and emptying gate structures, and completion of the navigation locks, would be scheduled prior to closure of the tidal dams. This schedule would permit use of gates for passing tidal flows during the closure operation and provide for continuity of navigation in the project area.

POWER FROM THE TIDAL PROJECT

The amount of electricity that the tidal project could generate was computed, taking into account many factors not specifically evaluated in the power studies for conventional hydroelectric projects. This close analysis was necessary because the influence of many factors was unknown and had to be determined before the power benefits of the project could be evaluated.

The ebb and flood of the tides cause the head on the turbines to change rapidly. Therefore, tidal power must be computed for successive short time intervals to be reasonably accurate. The net head on the turbines would vary with an average tide from about 5.5 ft. to 16.5 ft. in 12.4 hr. In addition, in each lunar month, or 29½ solar days, the tide would change twice from spring to neap and back to spring again. These conditions make computation of tidal power an exceedingly time-consuming process if done by conventional manual methods. For this reason, and because the problem

was highly repetitive, the computation was programmed for a high-speed electronic digital computer.

The program for the computer was made flexible, so that pool areas, filling and emptying gate characteristics, turbine and generator efficiencies, and turbine discharge could be changed easily. The results of the computations proved to be a powerful tool in selecting the type of turbine, including the blade setting for the selected fixed-blade propellor type, the rating of the generator, and the type and number of filling and emptying gates. By using varying pool areas, the computer furnished information that was invaluable in selecting the best tidal project arrangement. After the details of the turbines, generators, gates, channels, and pool areas were established, tidal power was computed for a period of 1 year. The indicated energy was 1,898 million kw.-hr. a year. This value was adjusted for factors not programmed into the computer, including slope of water surface in the low pool, leakage through the dams, fresh water inflow, fishways, project use of energy, and scheduled outages. After adjustments for items not included in the computer program, the net average annual generation of the tidal project is 1,843 million kw.-hr.

The installed nameplate capacity at the tidal power plant would be 300,000 kw. The generators could be

operated continuously at 15 percent overload at an increased but acceptable temperature. On this basis the plant could generate 345,000 kw. However, this high level of generation can be reached only during high tides, and then only during part of the tide cycle, unlike a conventional thermal power plant which can generate its rated capacity or more at any time. The dependable capacity of the tidal plant, therefore, is considerably less than the nameplate rating.

A steamplant can be assumed dependable 98 percent of the time. On a similar basis, a tide range (high tide level minus low tide level) was determined which was exceeded by 98 percent of the tide ranges. This amounted to a 13.2-foot range. The continuous power which the tidal power plant could generate through this tide range was then computed as a reasonable estimate of dependable capacity. This was 95,000 kw.

In the sense that the tides have not varied widely from their normal ranges of neaps and springs, the tidal plant output would be more reliable than a conventional hydroelectric development that may be subjected to prolonged periods of drought. Equipment failure and variation of the actual tide from the predicted tide would be the only elements, other than human failure, that would cause the output to vary.

Unscheduled shutdowns due to failure of equipment would not be excessive because standard type structures and equipment were used in the design. The number of filling and emptying gates and turbines is large enough so that a failure of any one unit would not cause a large reduction in tidal plant output. One filling gate stuck in the open or closed position would reduce average power output by about 3 percent and 1 percent, respectively. One inoperative generating unit would reduce output by about 1.4 percent.

Since the power output varies closely with the tide range, the accuracy with which the tides can be predicted is a direct measure of the predictability of power output. The predicted tide ranges used in this analysis are taken from the tide tables published by the United States Coast and Geodetic Survey, primarily for use by navigators. Closer predictions could undoubtedly be made. Power and energy predictions would thus be more accurate than determined from past records.

CHAPTER V - AUXILIARY POWER PROJECT DESIGNS

The four plans of power development selected for economic analysis include the Rankin Rapids river hydro project and the Digdeguash pumped-storage project as auxiliary power sources. In order to make cost estimates of the auxiliary power plants comparable in accuracy to the cost estimate made for the tidal project, preliminary designs were made for these two projects. (Wall Display: Regional Map)

RANKIN RAPIDS PROJECT

The Rankin Rapids auxiliary power project would be a conventional river hydro development. An earth embankment was found to be the least expensive dam that could be built from materials available at the Rankin Rapids site. The Saint John River would be diverted through two 24-foot-diameter tunnels in the right abutment prior to placement of the earth embankment across the river. The tunnels would be converted to low-level outlets by installing valves when the tunnels are no longer needed for stream diversion. The dam would be designed with top at el. 875 to provide 15 feet of free board above the maximum operating pool level at el. 860. The reservoir would provide 2.8 million acre-feet of active storage. The project layout is shown on this slide. (Slide 5-1: Rankin Rapids plan & section)

The powerhouse would be constructed in a deep excavation in the rock of the right abutment about 1,000 ft. from the toe of the dam. It would be about 584 ft. long with eight main-unit bays. Welded steel penstocks, 16 ft. in diameter, would convey water from the intake structure to the powerhouse. A chute spillway in the left abutment would consist of a concrete crest structure with gates, a concrete-lined chute and a stilling basin.

Access to the project would be gained over Maine State Highway 161, and by rail spur, constructed as part of the project, from the present railhead at St. Francis, Maine.

The power generating facilities would have a capability of 460,000 kw. at full turbine gate opening at a minimum net head of 269 ft. Eight main generating units would be provided, each rated at 50,000 kw. to correspond with the turbine output at best gate and average net head of 284 ft. The turbine speed would be 163.6 r.p.m. The generators could be operated continuously at 115 percent of nominal rating with an increased but acceptable temperature rise. Average annual energy would amount to 1,220 million kw.-hr. Dependable capacity of the tidal plant-Rankin Rapids combination would be 555,000 kw. at 60 percent load factor.

Four 120,000 kv.-a., 3-phase transformers would be located on the deck of the powerhouse over the draft tube. The transformers would be connected to the switchyard by 230-kv. aerial lines. The switchyard, located about 700 feet from the powerhouse on the right bank of the tailrace would handle four incoming lines from the powerhouse and three outgoing lines.

The concept of developing incremental capacity at Rankin Rapids as an auxiliary of the tidal power plant assumes that the Rankin Rapids project would be developed first to serve the needs of the utility market in Maine. A basic installation of 200,000 kw. of generating capacity would produce about 1,220 million kw.-hr. of energy, the average annual energy available at the site. An additional 260,000 kw. of dependable capacity would be installed specifically for firming the tidal project energy. When the tidal plant output drops below the load, the additional energy required would be borrowed from Rankin Rapids and repaid when tidal energy exceeds the load. The average annual energy of this combination would be the same as that of the tidal plant alone. The dependable capacity of the combination would be 355,000 kw.

The site of the Rankin Rapids dam and reservoir is in Aroostook County, Maine. The reservoir would extend (Slide 5-3: Rankin Rapids reservoir and real estate)

from the dam about 49 miles up the main stem of the Saint John River, 54 miles up the Allagash River, 19 miles up the Big Black River, and 17 miles up the Little Black River. Land required for the project totals about 99,500 acres. The area above the reservoir is wild, hilly land at an average elevation of 1,000 ft. above mean sea level. Cutting of pulp and timber is the main economic activity of the area. Most of the land required for the project is in large tracts of timber held mainly for pulpwood cutting. The relocation problem is considered minor.

International water rights on the Saint John River arise from the Treaty of August 9, 1842 between the United States and Britain (the Webster-Ashburton Treaty), which provides for common use of the waters of the Saint John River to promote commerce and transportation for the benefit of the United States and Canada. The only use made of the river in the sense of the Treaty is the floating of logs and pulpwood to downstream locations. The Rankin Rapids project would include a log chute to maintain this traffic. Anadromous fish do not pass the dam site since they are blocked downstream at natural obstacles.

The Rankin Rapids river hydro auxiliary could produce power from its first two generators about $3\frac{1}{2}$

years after construction is started, and all eight units would be on the line one year later. Construction of the project should be started at the same time as the tidal power project so that the new capacity would be available for transmission into Maine and New Brunswick at a rate approximately equal to the rate of load growth. In this way, the first two Rankin Rapids units would be on the line $2\frac{1}{2}$ years before tidal power and all eight units would be in service $1\frac{1}{2}$ years before tidal power is on the line.

If construction of the Rankin Rapids project is undertaken, the U.S. Fish & Wildlife Service recommend certain measures to mitigate fish and wildlife losses, including minimum releases, public access to the area, fish hatchery and rearing facilities, and other wildlife management programs.

DIGDEGUASH PROJECT

The Digdeguash auxiliary pumped-storage project was selected as the most feasible project of its type. The location of this project is near the mouth of the Digdeguash River at the north end of Passamaquoddy Bay. This auxiliary pumped-storage plant would pump seawater to a storage reservoir at times when surplus power is available and, by reversing the process, would generate power when the tidal plant output is less than the load

demand. The minimum requirements for the pumped-storage project were determined to be storage capacity equivalent to about 30 million kw.-hr. of energy. The dependable capacity of the pumped-storage installation was selected as 228,000 kw. on the basis that the tidal plant and this auxiliary would supply energy to the load at about 60 percent load factor.

Usable storage of 204,000 acre-feet and fresh water inflow would provide an output of 316 million kw.-hr. Deducting 400 million kw.-hr. required from the tidal plant for the pumping cycle, the annual energy of the tidal plant-Digdeguash combination would be 1,759 million kw.-hr. The combined dependable capacity would be 323,000 kw.

The dam site is in a narrow valley about 1,000 ft. from tidewater. The powerhouse would be constructed in a deep excavation in the left abutment immediately downstream from the dam. The reservoir would be connected to the powerhouse by an excavated approach channel, an intake structure, short high-level tunnels, and short steel penstocks above ground. A gated spillway would be located in the right abutment of the dam. The main dam, and the 3 saddle dams to close low spots in the reservoir rim, would be constructed of rock and earth fill with crest at elevation 190.

(Slide 5-5: Digdeguash plan and section)

The powerhouse would contain four dual-purpose units, each unit functioning as a turbine-generator to generate electric power and as a pump-motor to pump water into the reservoir. The runners would be rated at 110,000 hp. as turbines. The pump-turbine would be of the feathering-blade type rotating at 100 r.p.m. Because the blades overlap when fully feathered, they cannot be reversed. Therefore, runner rotation must be reversed when changing to either pumping water or generating electricity. The reversible motor-generators would be rated at 84,300 hp. as motors and at 68,300 kva as generators. Each pump-turbine would be connected to the reservoir by a separate penstock 20 ft. in diameter.

The area required for the reservoir and dam amounts to about 6,800 acres, the land being generally used for farming and woodlot operations. Relocation of roads, utility and communication lines, and cemeteries in the reservoir area would be required.

Construction of the pumped-storage project would require about 3 years. Completion would be scheduled at the same time as the tidal project.

CHAPTER VI - DEVELOPMENT OF COSTS

For determining the economic feasibility, it was necessary to estimate the costs of the tidal project and the auxiliaries. Estimating unavoidably deals with a great variety of numbers which are hard to remember. To avoid confusion, I will leave out all but the essential numbers, confining my talk to the criteria we used in estimating costs, and to the final results.

Even though the project described in the report is international, project costs were estimated in terms of United States currency, since investigation showed that the lower labor costs in Canada are offset by higher equipment costs and other factors. The estimates are based on costs prevailing in the United States in January 1958.

Quantities were determined in the conventional way from the designs described to you, previously. Since the designs covered only the major project features, check lists and bid schedules for other large projects were used to determine allowances for items not designed during the current study.

Unit prices are those which a contractor would bid. They include direct costs, an allowance for

indirect costs, and 10 percent profit. For important phases of the work, unit prices were built up rationally from equipment rental costs, equipment production, labor rates, and other factors.

Direct costs include labor, materials and supplies, equipment and plant. Labor costs were based on an 8-hour day and a 6-day week. The wage rate for the 6th day would be one and a half times the rate for the first five days. A 6-day week has been found necessary at other large and remote projects to attract a sufficient number of people in the trades required. The wage rates used in the estimate are those applicable in the Portland and Bangor area in January 1958. An allowance of 10 percent of the labor costs was added for insurance, taxes, and fringe benefits. On dredging operations, the allowance was 15 percent instead of 10 percent.

Material and equipment prices were based on information from manufacturers, dealers, contractors, construction records, and trade magazines. All equipment and material used in the project were assumed exempt from sales taxes, and the equipment or material originating in either United States or Canada was assumed free from import duties.

The cost of construction plant was based on rental rates and average annual cost of owning, operating, and maintaining equipment. The cost of small tools, estimated to be 5 percent of the labor cost, was included as a plant cost.

Indirect costs are made up of distributive and overhead costs which were estimated separately and then distributed to all payment items. Distributive costs, estimated at 5 percent of the direct costs, include mobilization and demobilization of equipment and employees, field office buildings, shops and warehouses, construction roads, and temporary construction facilities.

Contractors' overhead costs, estimated at 12 percent of the direct costs, consist of salaries of supervisors, engineers, timekeepers, and clerks, transportation of employees, office supplies and services, interest on invested capital, home office equipment, and bonds.

An allowance is commonly made in estimating project costs to account for unforeseen conditions which may rise during construction. The greatest uncertainty lies in the structure foundations which become fully visible only when excavation is complete and the foundation fully exposed. The allowance varies from 50 percent for

preliminary examinations to 5 percent on projects for which construction plans and specifications are complete. In the current study, the design of the powerhouse is more completely established than the design of the dams, and consequently the powerhouse might carry a lesser rate for contingencies than the dams. However, an overall allowance of 15 percent for contingencies was applied to the sum of the direct, distributive, and overhead costs.

Nine percent is allowed in the estimate for the expenses of the constructing agency for engineering, design, supervision, inspection of construction, and overhead.

The cost of the current survey is not in the estimated cost of the project.

The next slide shows the breakdown of cost for the tidal power project. The largest single item in the estimate is $151 million for the power plant. The total for the 3 sets of gates, including excavation and cofferdams, is nearly as much, amounting to $126 million. Dams are next, amounting to $80 million. Construction costs total $386 million. Contingencies amount to $58 million, and engineering, design, supervision and administration, $40 million. The total tidal project first cost amounts to $484 million. This amount

(Slide 6-1: Estimated cost of tidal project)

covers 75 million cu. yd. of earth work, 53 million in the dams, 1.5 million cu. yd. of concrete, and 180 thousand tons of steel.

The cost of the auxiliaries was estimated in the same manner as the cost of the tidal power project. In connection with reservoir clearing, it was estimated that the value of the timber and pulpwood on the 100,000 acres needed for the Rankin Rapids Reservoir would about pay for the limited cutting and clearing required on the margins of area.

The next slide compares the cost of the tidal power project with the cost of the various auxiliaries studied.

(Slide 6-3: Estimated cost of tidal project and auxiliaries)

Should predicted traffic by large vessels justify a large lock in the tidal project area, such a lock could be built in the Little Letite Passage area. A lock 800 feet by 80 feet with a 30-foot depth at mean low water could be built at an added cost of about $19 million.

The dams and structures would afford a good opportunity to connect the various islands to the mainland by public highways, thus providing a direct route from Lubec and Eastport, Maine to St. George, New Brunswick. This system of roads would cost a little over $8 million in addition to the cost of the tidal power project.

CHAPTER VII - ECONOMIC EFFECTS OF PROJECT

Economic surveys were conducted in Maine and New Brunswick to determine the capabilities of absorbing the power which would be produced by the tidal project and to determine the effect on the economy of the region.

ECONOMY OF MAINE

In 1950 the population of Maine was 914,000 and the total labor force numbered 345,000. Manufacturing is the largest income-producing and power-consuming segment of the economy of Maine, using nearly 2,700 million kw.-hr. of electricity in 1957.

The five leading manufacturing industries of Maine are paper and allied products, food and kindred products, leather and leather products, lumber and wood products, and textiles. These five industries accounted for 80 percent of Maine's total manufactured value in 1958, and nearly as large a proportion of the manufacturing employment.

The most important single element in the manufacturing economy of Maine is its forest products industry. Over 85 percent of the state's land area is in forest. Maine produces about 1.5 million tons of pulp and 1.6 million tons of paper per year.

The fishing industry has long been an important segment of Maine's economy and is the dominant factor in the economy of Washington County. Total fish landings have increased with population growth, and this trend is expected to continue.

Agriculture provides less than 10 percent of the total personal income in Maine.

Recreation is an increasing element of the state's economy.

Construction of the Passamaquoddy tidal power project with an auxiliary power plant would have a favorable impact on all segments of the economy of Maine. The accompanying growth in the demand for electricity could readily absorb the United States' share of the output of the tidal power plant and its auxiliary. In addition to supplying an important block of power to assist in meeting the needs of the growing power markets, the construction and operation of the tidal power project and its auxiliary would serve also as a catalytic agent in the regeneration of the economy of Maine, particularly in Washington County.

Construction of the tidal power project and the Rankin Rapids auxiliary would also produce an important short-term economic impact on the economy of Maine. During the six-year construction period of the tidal

power project alone, total investment outlays in Maine, and to a major degree in Washington County, would amount to approximately $100 million or more. This investment would generate an additional $100 million of expenditures, increasing total income in Maine by at least $200 million. This additional income would exert an important upward pressure on the construction industry and on wholesale and retail trades.

In addition to long-term beneficial economic effects, the economy of Washington County would be transformed during construction of the project by the influx of several thousand workers and the generation of substantial new income in wages alone.

ECONOMY OF NEW BRUNSWICK

In 1955 the population of New Brunswick was 547,000, with a labor force of 171,000 and a gross provincial product, the at-market value of all goods and services produced in a year, of $530 million (Canadian currency, 1955 price level). Corresponding figures projected to 1980 are: population, 825,000; labor force, 248,000; and gross provincial product, $1,035 million at 1955 price level.

Economically, the most important industries are mineral production, pulp and paper, lumber and wood, fishing, agriculture, secondary manufacturing (largely

food and beverages) and construction. The value of services, i.e., those activities resulting in invisible products rather than physical objects, was nearly 50 percent of the gross provincial product in 1955, and is expected to maintain about the same relative position in the foreseeable future.

The Canadian half of the power from the tidal project and its auxiliary would be absorbed into the transmission and distribution system of The New Brunswick Electric Power Commission. Power from the proposed project would have the same effect on the general economy of the Province of New Brunswick as any other block of power of similar size and cost developed to satisfy the growing load demand.

An estimated $100 million would be spent in New Brunswick for project construction materials. The spending of this money would probably generate another $100 million in trade which would benefit the Provincial economy.

In recent years there has been a notable absence of growth in the economy of Charlotte County. As a result of the construction of the Passamaquoddy project, the short-term benefit to the county economy would be substantial. The new income from wages alone would have a marked effect on the county retail trade. Any

venture as extensive as the Passamaquoddy project would provide considerable impetus to the lumber and other industries in Charlotte County. An additional, small but continuous benefit would accrue from the maintenance labor and expenditures for project operation and from the visitors to the tidal project.

SPECIFIC EFFECTS

In addition to the general effect on the regional economy as just described, the tidal project and its auxiliary would have certain specific effects.

Construction of the tidal project would result in some beneficial and some adverse effects on the fisheries industry. Inclusion of fishways in the tidal project structures for the passage of anadromous fish would provide continuity of existing natural conditions. Any other direct damages would be resolved by appropriate remedial construction or monetary settlement. Certain remedial measures would be included in the auxiliary project at Rankin Rapids to preserve the sport fishing on the Allagash and Saint John Rivers.

Recreation attractions and attendant facilities would be greatly benefitted by the proposed project. It is estimated that 800,000 persons would visit the tidal project alone, initially, and probably this number would increase in succeeding years.

Navigation in the tidal project area would be benefitted by having less variation in water levels and currents in the pool areas. Also, the higher prevailing water surface in the high pool would increase the controlling navigation channel depth to Calais, Maine, and to St. Stephen, New Brunswick, by more than 15 feet.

The 7 miles of tidal dams would afford an opportunity to connect the Canadian coastal highway at St. George, New Brunswick, with the United States coastal highway at Eastport and Lubec in Maine.

The construction of the tidal project would have no effect on the defense planning of either Canada or the United States. However, the Passamaquoddy project with the Rankin Rapids auxiliary would save more than a million tons of coal or nearly 6 million barrels of oil a year.

CHAPTER VIII - POWER UTILIZATION

One of the important components of the present investigation is a study of the markets which could absorb the output of the tidal project, with and without an auxiliary, within a reasonable time after completion. Related to this and to the economic evaluation of the tidal project is a determination of the physical features and annual costs of the transmission facilities required to deliver the output of the project to the markets of Maine and New Brunswick.

POWER MARKETS

An examination of the various existing and potential markets indicated clearly that the output of the tidal project can best be utilized by the growing requirements of the utilities in Maine and New Brunswick.

(Slide 8:1 Power requirements, Maine utilities)

This slide shows the past and estimated future utility power requirements in Maine over the period 1940-1980, inclusive. The upper line on the plot indicates energy demand, with units of measurement at the left side; the lower line indicates capacity requirements with scale at the right side. The projected values of 7,600 million kw.-hr. and 1.4 million kw. for the year 1980 are nearly 3 times greater than the corresponding actual requirements for the year 1957.

In similar manner the power requirements of the New Brunswick utilities for the same period are shown on the next slide. Here we find the projected requirements for 1980 are 3,000 million kw.-hr. and 600,000 kw. or about 4 times greater than the 1957 requirements.

(Slide 8-3: Power requirements, N.B. utilities)

A comparison of the estimated future utility loads in Maine and New Brunswick with the capacity available at the present time indicates that considerable amounts of new generating capacity must be added by the utilities to their power supply resources in the next twenty years. The required capacity additions in both areas are shown on the next slide.

(Slide 8-5: Additional dependable capacity required)

For adequacy of service the dependable capacity of a utility system must equal the sum of the peak demand to be carried and a reasonable amount of reserves. Reserves are necessary to allow for the removal of generating units from service for routine maintenance, for protection of service during breakdowns of equipment, and as a safeguard against errors in load forecasting. Adding required reserves and expected peaks gives the total requirements for dependable capacity.

For carrying their future loads the utilities will have in operation all of their present capacity less retirements due to physical and technological obsolescence.

Expected retirements of fuel-electric capacity are 53,000 kw. by 1970, and 79,000 kw. by 1980. No retirements of hydro-electric plants are expected during the same period.

Definite scheduling of capacity additions is made usually three to four years in advance. This is the time required to complete construction of a new facility of standard type. As of January 1, 1958, the utilities of the two areas scheduled the addition of 113,000 kw. of fuel-electric capacity before the end of 1962. No new hydro capacity has been scheduled for construction in the near future, even though several sites of potential hydro power have been investigated in recent years.

The total of all capacity that will be definitely available for carrying future utility loads adds up to 904,000 kw. in 1970, and to 878,000 kw. in 1980. As shown on the bottom line of the tabulation on the slide, the additional dependable capacity required in Maine and New Brunswick is 540 thousand kw. by 1970 and 1,382 thousand kw. by 1980.

Thus the power market surveys revealed that the need for additional capacity to meet future demands in both Maine and New Brunswick could readily absorb by 1980 the 555,000 kw. of dependable capacity from the

tidal plant and Rankin Rapids, the largest project combination studied.

TRANSMISSION LINES

Each combination of tidal project and auxiliary would require a distinct layout of lines, substations and other facilities to deliver its output to the utility markets of Maine and New Brunswick. Transmission voltages, number of circuits, size and material of conductors, and type of supporting structures would be determined in consideration of the amount of power to be transmitted, distances involved, and permissible losses and voltage regulation in present-day utility practice. The same factors would determine selection of transformers and all other equipment at receiving and sending substations.

The capital costs of the transmission facilities for delivering project output to Maine were based on data obtained by the Federal Power Commission from the utilities of the State. Annual fixed charges were calculated on the basis of federal financing at $2\frac{1}{2}$ percent interest rate. Operation and maintenance expenses were estimated on the basis of current utility practice in the area. The estimated capital and annual costs of transmission lines in New Brunswick are based on data furnished by The New Brunswick Electric Power

Commission, with fixed charges based on a 4 1/8 percent interest rate.

The next slide shows the required transmission facilities for delivering to market the output of the tidal project if operated without an auxiliary. In this case the dependable capacity is 95,000 kw. and the average annual energy output is 1,842 million kw.-hr. Half of this output would be delivered to Maine, and an equal amount to New Brunswick. (Slide 8-6: Transmission lines, tidal plant alone)

For delivery to Maine the tidal power would be first stepped up to 230 kv. at the step-up substation of the project. Approximately 25,000 kw. of firm power would be delivered over a 230-kilovolt double circuit line to a load in the vicinity of the project and the remainder to the Bangor Hydro-Electric Company at the Veazie substation near Bangor, Maine. Non-firm or secondary energy would be delivered to the Bangor Hydro-Electric Company at Veazie and to Central Maine Power Company at the Winslow substation near Waterville. The capital costs of the transmission lines amount to $11,360,000 and the annual costs to $661,000.

The next slide shows the transmission facilities required to deliver the output of the tidal project and of Rankin Rapids as auxiliary. In this combination, the capacity and average year energy available (Slide 8-7: Transmission lines, tidal plant and Rankin Rapids)

for load-carrying purposes are 555,000 kw. and 3,062 million kw.-hr. For the purpose of this study it was assumed that the output of each project in this combination would be shared equally by Maine and New Brunswick.

The 460,000 kw. produced at Rankin Rapids would be transmitted first over a 3-circuit 230-kv. line to a substation near Presque Isle, Maine. At this point, power allocated to New Brunswick would be stepped down to 138 kv. and transmitted at this voltage over a double circuit line to Beechwood, New Brunswick. Some 25,000 kw. of the power available for use in Maine would be delivered at Presque Isle to the Maine Public Service Company. The remainder would be transmitted over a double circuit 230-kv. line to the Veazie substation near Bangor, Maine, where 40,000 kw. would be stepped-down to 115 kv. for delivery to the Bangor Hydro-Electric Company. At Veazie, power from Rankin Rapids would be combined with power delivered to this substation from the tidal project over a double circuit 230-kv. line. The Central Maine Power Company would receive project power at the Winslow substation near Waterville and at the Gulf Island substation near Lewiston. These two delivery points will be served by a double circuit 230-kv. line extending westward from the Veazie

substation. The capital costs of the lines which would deliver project and auxiliary output to utilities in Maine would amount to $30.8 million and the annual costs, to $1.7 million.

Since the markets of Maine and New Brunswick are distant from the tidal project and its auxiliary, the lines are necessarily long and costly. However, their large carrying capacities and their strategic location makes them particularly valuable for interconnecting and coordinating, with considerable advantage, the utilities of Maine and New Brunswick, and possibly other parts of New England and the Maritime Provinces.

CHAPTER IX - PROJECT EVALUATION

To determine the economic justification of the tidal power project, annual benefits and costs were computed, with and without auxiliaries. It is assumed that the project is justified when power needed to meet expected requirements can be produced at a cost no greater than that of the alternative source of power most likely to be used. The degree of economic justification is measured by the ratio of annual benefits to annual costs.

It was assumed that the first costs of the project would be shared equally by the United States and Canada, just as the power output would be shared. Differences in interest rates and in other economic factors required separate analyses of economic justification for the United States and Canada.

VALUE OF POWER

The value of the output of a hydroelectric power project delivered to its market is measured by the cost of producing an equivalent supply of power at a suitable alternative source and delivering the alternative power to the same market. The alternative power supply is taken as a modern, conventional steam-electric plant suited to the future power requirements of the selected market.

The cost of the alternative steam-electric power was computed according to practices common to each country. In Maine, the alternative power would be privately financed; in New Brunswick, it would be publicly financed.

At-market values of tidal project power are obtained by estimating the costs of producing an equivalent supply of power from alternative steam-electric plants, adding the cost of transmission to selected load centers, and finally by applying adjustments for hydro-steam differentials. The resultant at-market values are then reduced by the costs of transmitting the output of the tidal project to the same load centers, thus yielding the at-site power benefits. The at-site benefits are compared with at-site costs to determine economic justification.

The alternative steam-electric plants were located to deliver to the selected markets the same amount of power as the tidal project, with or without auxiliaries, considering also the availability of condensing water and of waterborne fuel. In Maine, alternative steam plants were assumed at Caribou, Eastport, Belfast and Yarmouth. In New Brunswick, the alternative plants were assumed at Saint John and Bathurst.

(Wall Display: Regional Map)

In the analysis of steam-electric power costs, the total annual costs are separated into fixed and variable components. Annual fixed costs consist of interest, depreciation, interim replacements, insurance, and interest on investment in reserve fuel supply, fixed components of total production expense, and administrative and general expenses. In Maine, taxes constitute another annual fixed charge. The New Brunswick Electric Power Commission, being publicly owned, pays no taxes. The remaining costs of power generation consist of the variable components of fuel and of operation and maintenance expenses. These items are also known as incremental energy costs.

Fixed charges are those elements of annual cost that are a direct function of the capital investment in a facility. These are made up of interest, depreciation or amortization, interim replacements, insurance and taxes. Estimated annual fixed charges as a percent of capital investment for steam-electric plants located in Maine amount to 11.94 percent and for New Brunswick plants 5.899 percent. On this basis the annual cost of power at the bus-bar of the alternative steam-electric plants is shown on the next slide. Separate values were computed for capacity (kilowatts) and energy (kilowatt-hours). The capacity cost in the United States is

(Slide 9-2: Estimated Bus-Bar Cost of Steam-Electric Power)

much greater than in Canada because of the greater United States fixed charges. Fuel makes up most of the energy cost which, for the major plants, is nearly the same in the two countries.

The at-market cost of alternative power includes, in addition to the cost of generation, all costs of transmitting the alternative plant output to the principal load centers. Since the alternative power plants used for evaluation of the tidal project and its auxiliaries would be located reasonably close to the load centers, or, in New Brunswick, on existing high-tension networks of the utilities, the transmission lines and substations for these plants would be considerably smaller than those needed for the tidal project and its auxiliary.

The at-market values of power from the tidal project, with or without an auxiliary source of supply, are shown in the first column of the next slide.

(Slide 9-4: At-Market and At-Site Values of Tidal Power)

In order to obtain at-site values, we subtract from the at-market values the annual costs of transmission for each tidal project development. The at-market values in the last column of the slide constitute the benefits which the tidal power project, with or without an auxiliary, would provide.

The Rankin Rapids auxiliary would have 2.8 million acre-feet of storage to regulate the river flows. For

example, at the existing downstream plant on the Saint John River at Beechwood, New Brunswick, the low flow would be increased from about 2,000 c.f.s. to over 5,000 c.f.s. The stream flow regulation would increase substantially the energy generated at existing downstream plants and, to a lesser extent, the dependable capacity. Increasing the installed capacity at existing plants or constructing new plants on the lower Saint John River would result in additional benefits.

Since full evaluation of the ultimate downstream benefits is outside the intent of the tidal power investigation, the power benefits downstream on the Saint John River were estimated considering only the existing installations at Grand Falls and Beechwood hydroelectric power plants. On the basis of this limited study, the downstream benefits to the tidal project - Rankin Rapids combination would amount to 180 million kw.-hr. of energy and 5,000 kw. of dependable capacity. These benefits were assumed divided equally between United States and Canada.

COST OF POWER

Having determined the value of tidal power, we will take up next the cost of generating tidal power.

The annual cost of the tidal power project, with or without an auxiliary, includes the annual costs of

maintaining and operating the project and the financing charges.

Because the tidal power project with its auxiliary would be an international project of considerable magnitude, it was assumed that the project would be built with funds furnished by the governments of the two countries.

Interest on the United States investment is computed at the rate of 2½ percent a year. This rate is used by the United States Bureau of the Budget for evaluating water resources projects. The Canadian interest rate is 4 1/8 percent, the interest rate used in January 1958 for loans to crown corporations and provincial governments.

Interest during construction was computed at the appropriate interest rate for one-half of the construction period. The initial investment is the sum of interest during construction and the project first cost.

The tidal project combinations were evaluated using amortization periods of both 50 and 75 years. Fifty years represents the period commonly used in both the United States and Canada for recovering investment from water resources projects.

General experience indicates that about 25 percent of the major items of mechanical and electrical equipment

would require replacement after 30 years of operation. Using this estimate, the deferred costs of major replacement items were computed on an annual basis over the amortization period of the project, and included in the annual costs. An allowance of 0.05 percent of the first cost was included in the annual costs for self-insurance to provide against accidents.

Annual operation and maintenance costs, including labor, supplies, and contract services amount to $874,000 for the tidal project, $230,000 for the Rankin Rapids auxiliary, $57,500 for incremental capacity only at Rankin Rapids and $178,000 for the Digdeguash pumped-storage auxiliary.

If the tidal project and auxiliary are not built, the utility companies must build other generating plants to meet the growing power load. The private utilities in Maine would pay taxes on these facilities. On the other hand, the tidal project and its auxiliary, assumed to be quasi-governmental, would pay no taxes. This represents a loss in revenue to the people of the United States. Evaluation of United States water resources projects customarily includes an item for taxes foregone in the annual economic cost of a project. However, this problem does not exist in Canada because the New Brunswick Electric Power Commission does not

pay taxes. The Engineering Board concluded, because the tidal development is an international project, that taxes foregone in Maine would not be included.

The results of the computation of economic justification for 50-year amortization are summarized on the next slide. Benefit-cost ratios less than one show a project not justified economically. Ratios greater than one indicate that projects are economically justified. Only the United States half of the tidal project with Rankin Rapids as an auxiliary has a ratio greater than one. For 75-year amortization, the benefit-cost ratios are generally 17 percent larger for the United States and 9 percent for Canada.

(Slide 9-5: Benefits and Costs, 50-year Amortization)

Taxes foregone would increase the annual economic cost of the United States half of the project by about $9 for each kilowatt of dependable capacity. This would reduce the benefit-cost ratio from 1.31 to 1.10, on a 50-year amortization basis, for the United States part of the tidal plant-Rankin Rapids combination.

CHAPTER X - CONCLUSIONS

The conclusions of the survey of the international Passamaquoddy tidal power project are summarized as follows:

(1) A tidal power project using the waters of Passamaquoddy and Cobscook Bays can be built and operated. The two-pool type of project is best suited for the site conditions in the area and the power markets it would serve. The tidal project arrangement selected makes best use of the site conditions.

(2) The first cost (construction cost) of the tidal power project by itself would be $484 million. With interest during construction, the investment would be $532.1 million. The tidal power project would have an installed capacity of 300,000 kw. and a dependable capacity of 95,000 kw. Average annual energy would be 1,843 million kw.-hr. However, for maximum power benefits, the tidal power project would have to be combined with an auxiliary power source.

(3) The most favorable project combination is the tidal power project operated in conjunction with a river hydroelectric auxiliary built at the Rankin Rapids site on the upper Saint John River in Maine.

The combined cost of the tidal project and the Rankin Rapids auxiliary is $630 million. With interest during construction, the investment would be $687.7 million. The dependable capacity of this combination would be 555,000 kw. and average annual generation would be 3,063 million kw.-hr.

(4) Construction of the tidal project - Rankin Rapids combination would increase low flows in the lower Saint John River by a considerable amount, thus increasing substantially the usefulness of the river for downstream generation of power. Downstream benefits accruing to existing power plants were included in the economic evaluation.

(5) The combination of the tidal power project, and the installation and use of 260,000 kw. of capacity only at Rankin Rapids for firming up the output of the tidal power project, would cost $515.5 million. With interest during construction, the investment would be $565.7 million. This combination would provide a total dependable capacity of 355,000 kw. and an average annual generation of 1,843 million kw.-hr.

(6) The tidal power project and the Digdeguash pumped-storage auxiliary would cost $518.5 million. With interest during construction, the investment would be $578.9 million. The dependable capacity

would be 323,000 kw. and average annual generation would be 1,759 million kw.-hr.

(7) The total output from the tidal power project and Rankin Rapids hydroelectric plant can be absorbed readily by the growing utility markets of Maine and New Brunswick.

(8) Because of differences in interest rates prevailing in the two countries, and because of different values of alternative power, it was necessary to compute separate benefit-cost ratios for United States and Canada. Economic evaluations, assuming 50-year and 75-year amortization periods, and assuming that power and project first costs would be equally divided between United States and Canada, are tabulated on this slide.

(Slide 9-6: Benefit-Cost Ratios and Cost of Power)

(9) The inclusion of taxes foregone with project costs is not the practice in the economic justification of public projects in Canada, and due to the international nature of the project, such taxes have not been applied to United States' costs. However, if they were included in United States' costs, the benefit-cost ratio of the most favorable project combination would be reduced to 1.10 for the 50-year amortization period and to 1.25 for the 75-year period.

(10) By including appropriate remedial measures in the design of the tidal power structures, the

construction, maintenance, and operation of the tidal power project would have only a minor residual effect on the fisheries of the region.

(11) Considerable annual recreation benefits would grow out of the construction and operation of the tidal power project. However, the monetary value of these benefits was not included in the economic evaluation.

(12) Assuming an equal division of power output and of first costs between United States and Canada, construction of the tidal power project with all of Rankin Rapids as auxiliary is not an economically justified project for Canada.

(13) The Passamaquoddy tidal project and Rankin Rapids combination, if built entirely by the United States, at an interest rate of $2\frac{1}{2}$ percent, is economically justified.

CLOSING STATEMENT

This briefing has been, of necessity, a greatly condensed summary of a major engineering and economic survey of a large project of international importance. In order to cover the entire subject, only the most important facts and figures have been cited which lead to the conclusions reached. Discussion of numerous interesting and unusual features of the Passamaquoddy tidal project with its auxiliary, and of the many alternative schemes investigated, is beyond the scope of this presentation.

LIST OF EXHIBITS

Wall Displays (Roll curtains)

1. Regional Map

2. Selected Plan, General Arrangement (Tidal project)

Slides ($3\frac{1}{4}$" x 4") in order of use
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